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Author(s): Broussard, Leah Jacklyn

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The background of the slide is a collage. On the left, there is an aerial photograph of the Los Alamos National Laboratory campus, showing various buildings, parking lots, and surrounding hills. On the right, there are two images of laboratory equipment. The top right image shows a close-up of a circular component, possibly a neutron detector or part of a spectrometer, with a central orange-colored disk. The bottom right image shows a more complex piece of equipment, possibly a neutron scattering instrument, with various pipes, cables, and structural components.

Actinide Studies with Ultracold Neutrons

Leah Broussard

Los Alamos National Laboratory

October 11, 2014

Effects of Fission on Surrounding Material

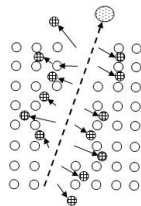
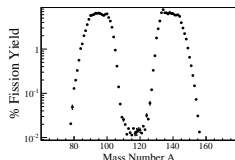
Typically 2 fragments emitted

- $A \sim 100$, $E \sim 100$ MeV, $\frac{v}{c} \sim 10\%$
- Range $\sim 10 \mu\text{m}$

Effect on material

- Very energetic, heavy, charged particles
- How is energy deposited in material?
- Damage to the material?
- Near material surface: ejection of matter
- Differentiate between theoretical models

^{235}U fission fragments



Why study nuclear material aging?

- Nuclear fuels
- Stockpile stewardship
- Lifetime of materials in space



Inducing Fission with Ultracold Neutrons

Experimental evidence

- Many previous measurements of sputtered atoms per fission
- **Significant disagreement in yield, distribution!**
- Key to differentiating models

New Technique for understanding sputtering

- Induce fission using Ultracold Neutrons
- Excellent control of neutron energy
- Very sensitive probe of fission as function of depth



LANL: Unique Position for work

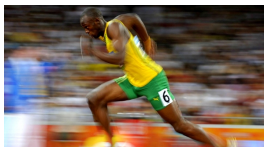
- LANSCE: one of world's brightest sources of UCN
- Expertise in fabrication and analysis of actinide targets

Ultracold Neutrons

Class	Energy	Source
Fast	$> 1 \text{ MeV}$	Fission reactions / Spallation
Slow	$\text{eV} - \text{keV}$	Moderation
Thermal	0.025 eV	Thermal equilibrium
Cold	$\mu\text{eV} - \text{meV}$	Cold moderation
Ultracold	$\leq 300 \text{ neV}$	Downscattering

How cold is Ultracold?

- Temperature $< 4 \text{ mK}$
- Velocity $< 8 \text{ m/s}$
- Usain Bolt $\sim 12 \text{ m/s}$



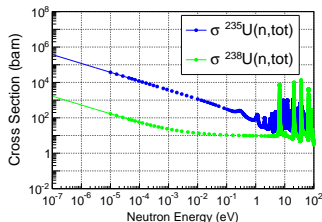
UCN can be bottled

- Gravitational ($V = mgh$): $100 \text{ neV} / \text{meter}$
- Magnetic ($V = -\vec{\mu} \cdot \vec{B}$): $60 \text{ neV} / \text{Tesla}$
- Material $\left(V = \frac{2\pi\hbar^2 Nb}{m} \right) \left\{ \begin{array}{ll} {}^{58}\text{Ni} : & 335 \text{ neV} \\ \text{DLC} : & 250 \text{ neV} \\ \text{BeO} : & 250 \text{ neV} \\ \text{Cu} : & 170 \text{ neV} \end{array} \right.$

Predictions for UCN-induced Fission in Uranium

Uncharted energy regime

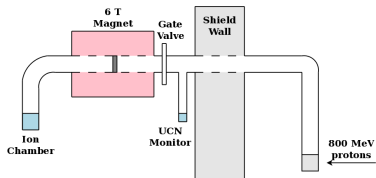
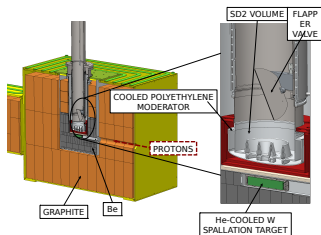
- 3 orders of magnitude lower than ever explored
- Very high theoretical cross section
 $\sigma \sim \frac{1}{v}$
- 300 neV UCN: 2.16×10^5 barn



Control depth of fission event

Range of UCN in uranium (μm)						
	DU	NatU	SEU	LEU	HEU	VHEU
% ^{235}U	0.2	0.7	2	5	20	100
200 neV	118	66	312	13	4	0.8
300 neV	144	81	38	17	4.5	0.9
400 neV	191	101	45	20	5	1

Ultracold Neutron Facility at LANSCE



UCN Source

- 800 MeV proton beam + W target \rightarrow spallation neutrons
- single scatter in SD₂: CN \rightarrow UCN + phonon
- High density at shield wall: 50 UCN/cc
- Pulsed beam: Low background

Experimental Area

- UCN bounce along guides. through Al window, into detection chamber
- 6 T magnet = near 100% polarization

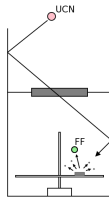
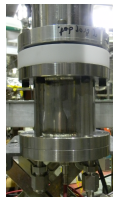
Fission Rates

Detection chamber

- Cylindrical ion chamber

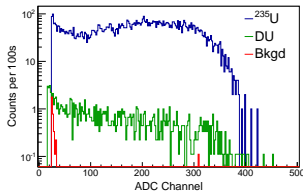
^{238}U

- 2.25 cm diameter, 1 mm thick disk of DU ($\sim 0.2\% \text{ } ^{235}\text{U}$)
- Rate: $(1.3 \pm 0.8) \times 10^{-4}$ fission/UCN



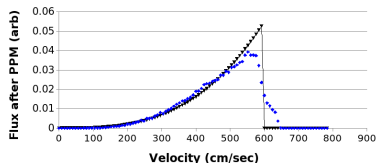
^{235}U

- 2.2 cm diameter, 1 mm thick disk of HEU ($> 80\% \text{ } ^{235}\text{U}$)
- Rate: $(1.90 \pm 0.02) \times 10^{-2}$ fission/UCN



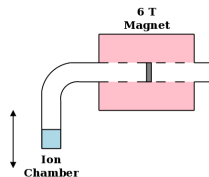
Varying UCN Energy

Simulated UCN energy spectrum after magnet



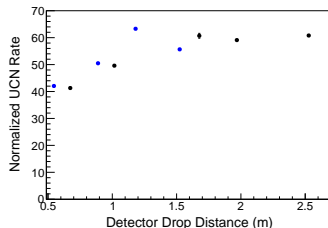
Two primary methods for control

- Magnetic field (60 neV/T)
- Gravity (100 neV/m)



Gravity scan

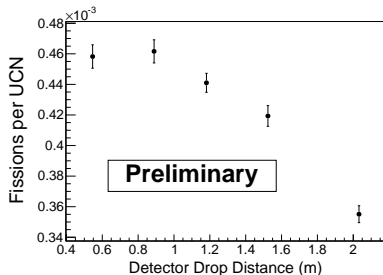
- Adjust height of ion chamber
- Sensitive to geometry, guide quality
- Al window: 50 neV barrier
- $^3\text{He} + n \rightarrow p + t$



UCN-energy dependence of fission rates

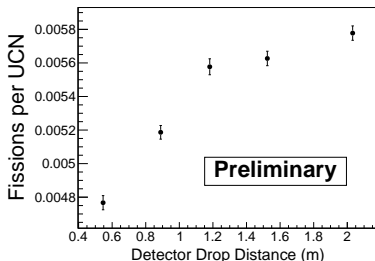
DU sample

- Electropolished, 2.25 cm diameter, 1 mm thick disk
- Measured fission rate decreases with UCN energy



^{235}U sample

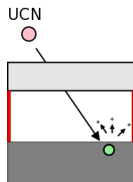
- Thin sample: 30 μg heavily oxidized ^{235}U on tape
- Measured fission rate increases as UCN energy increases



Sputtering from UCN-induced fission

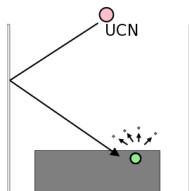
Exposure to Silicon wafer

- 1" diameter, 475 μm thick, polished wafer
- Exposed to 2.2 cm diameter, 1 mm thick electropolished DU disk
- 3×10^7 total UCN in chamber
- 0.18 μg ^{238}U collected on wafer
- Analyze with scanning probe microscopy



Exposure to Ni cylindrical foil

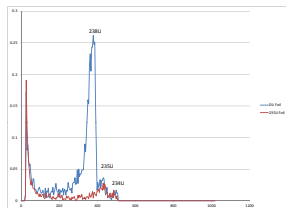
- 0.005" Ni foil, 1.15" diameter, 2.835" height
- UCN bottle: Ni material potential ~ 300 neV
- Exposed to DU disk and 30 μg ^{235}U thin sample



Sputtering on Nickel foil

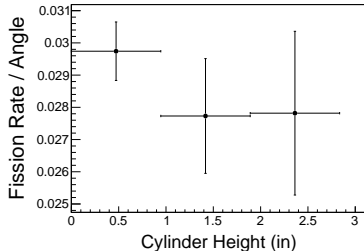
Expose to DU disk and HEU film

- Each sample exposed to $\sim 10^8$ UCN
- Determine yield from α decay rate in ion chamber
- Can distinguish α 's from ^{238}U , ^{235}U decay

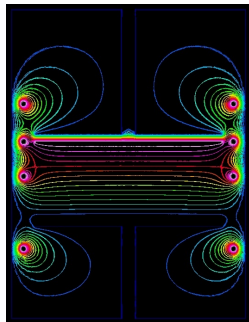
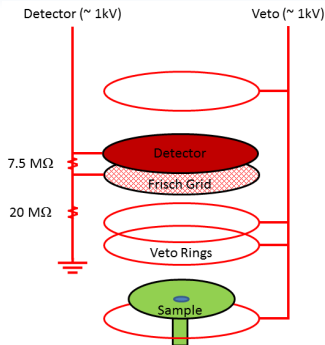


Angular distribution

- Mask vertical sections of foil
- Results from DU foil
- Distribution \sim isotropic



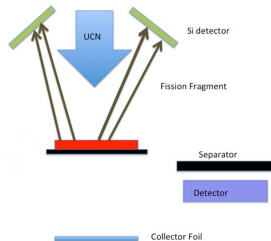
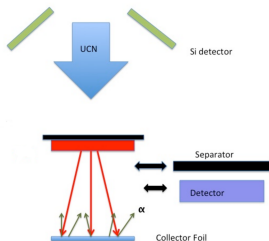
Low Background Analysis Chamber



Design Goals

- Amount of sputtered material very low
- Veto signals originating outside region of interest
- Background < 1 count/hour
- Undergraduate Student Project: Jose Ortiz, UW

Characterize Ejected Material In-Situ



Key questions:

- How much comes off?
- Size distribution vs. depth/surface quality?
- Kinetics vs. depth?
- Effect of surface preparation?

Summary

First observation of UCN-induced fission

- Previously no fission data at these energies
- Initial characterizations of UCN energy dependence, material thickness

First observation of sputtering from UCN-induced fission

- Proof of principle demonstrated

2014 Accelerator Cycle

- New beamline for parasitic running
- Sample handling to eliminate contamination
- Well-characterized samples of different geometries